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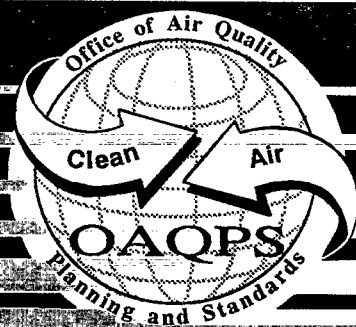
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# STUDIES ON ALTERNATIVELY FUELED BUSES





**SUMMARY OF SELECTED LITERATURE ON  
LAND-USE TRANSPORTATION INTERACTIONS AND  
ALTERNATIVELY FUELED BUSES**

**Volume 2: Alternately Fueled Buses**

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Alternatively Fueled Buses**

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## **INTRODUCTION**

Continuing challenges in attaining National Ambient Air Quality Standards and the passage of the Clean Air Act Amendments of 1990 have inspired renewed efforts to identify and implement innovative new control strategies. In most urban areas, motor vehicles contribute approximately 50 percent of emissions involved in ozone and approximately 90 percent of carbon monoxide nonattainment problems. Increased reliance on alternative fuels, increased understanding and use of the interdependence of land use and transportation, and alternative technologies such as electric vehicles are among the many innovative strategies under discussion. This volume provides a preliminary bibliography of literature relating to alternatively-fueled buses. Volume one of this set provides a review of literature relating to land use/transportation/air quality interactions.

It is important to note that there is a specific focus for each subject area and that the scope of this bibliography is not intended to cover either the vast body of related research (i.e. alternative fuels in general), or to comprehensively review all material relating to alternative fuels in buses. Rather it is intended to provide a source of information on the scope and nature of current research. State and local agencies wishing to use such strategies should also plan to draw on sources other than those reviewed here.

The remainder of this report is organized as follows: (1) a summary discussion of the importance of land use/transportation interactions and examples of research relating to strategies utilizing these interactions, (2) bibliography of land use/transportation material, including brief abstracts (one to two paragraphs) of each reference, (3) summary of alternatively fueled buses, and (4) bibliography of alternatively fueled bus studies, including abstracts. Items one and two are included in volume one; items two and three are included in this volume. Each volume is separately bound.

## **ALTERNATIVE FUELS IN BUSES**

This section of the draft bibliography presents the results of a search of a number of potential data sources related to the use of alternative fuels in heavy-duty applications, more specifically in buses. An on-line search of the TRIS database, which lists transportation-related documents, was conducted and almost one thousand references provided by that search have been examined. In addition, numerous individuals engaged in research on this topic have been contacted, including those in the academic community as well as in government and private industry. Table 2 summarizes a number of key observations from this review.

The materials provided here consist mainly of scientific papers from the academic and consulting sectors in which one aspect of alternative fuel use in heavy-duty vehicles is explored. For instance, several papers discuss the design and testing of engines for use with alternative fuels (Chandler, et al, 1991; Gilbert and Gunn, 1991; Wachter, 1990).



Others focus on how diesel fuel can be used more cleanly in heavy-duty applications (Giuliani and Murphy, 1991; Small, 1988; Unnasch, 1986). Dual-fuel vehicles are discussed in a few of the papers, although it is generally concluded that dedicated fuel vehicles provide greater environmental and economic benefits (EPA, 1990a; Klausmeier and Draves, 1991).

A number of transit agencies in the U.S. and in other countries have experimented with alternatively fueled buses, and their experiences could prove to be extremely valuable to those agencies currently exploring the possibility of purchasing such buses. Thus, several reports which could be classified as case studies are also provided in this bibliography, including reports from fleet operators in Denver, Seattle, Tulsa, Southern California, New York and Ontario. Table 3 is excerpted from one such report, "Summary of Alternative Fuel/Clean Air Technology Buses in North American Transit Use" (Meloche, 1990), and includes the names of transit systems currently (as of April 13, 1990) using alternatively fueled vehicles, the alternative technology employed, fleet size, and vehicle manufacturer.

It is clear that methanol and compressed natural gas are the alternative fuels that have received the most attention from researchers and that have been chosen most often by transit agencies for demonstration projects. Both of these fuels produce significant air quality benefits, and the conversion costs are usually not as high as they are for ethanol or other types of fuels. Diesel fuel is rarely included in the category of "alternative fuels" unless its use has been modified in some way, usually through the installation of particulate traps. Studies are included here which compare the emissions and cost effectiveness of these traps with other forms of alternative fuels.

Most of the reports included in this bibliography discuss the costs associated with converting bus fleets to alternative fuels. While the direct cost of using alternative fuels is almost always significantly higher than the cost of diesel or gasoline, many of the analyses included here fail to quantify the social benefits expected from the use of alternative fuels. As pointed out in the paper by R.F. Webb Corporation (1990), the economics of large-scale conversions of transit buses to alternative fuels will be favorable only when benefit calculations include social benefits such as emissions reductions and energy security. Clearly, these considerations should be treated as important factors in any cost/benefit analysis, because they are the major reasons for encouraging the use of alternative fuels in the first place.

### **Bibliography of Material on Alternatively Fueled Buses**

Bol, M. A. and G. B. Hamilton. 1989. "Economic Life Cycle Costs of Methanol in Diesel Applications." VIII International Symposium on Alcohol Fuels.

Based on the experiences of the Canadian Methanol In Large Engines (MILE) Project, this paper seeks to evaluate the projected economic life cycle costs of methanol in transit bus operation. This analysis addresses the major costs of operating methanol transit buses, including methanol fuel price and distribution, engine costs, maintenance and fueling operations. Estimates of life cycle costs for



other emission reduction options such as particulate traps and low sulfur fuel are also provided. The time frame for the scenario addressed by this paper is 1991-92, when it is assumed that methanol engines will be commercially available from at least one supplier. A range of estimated costs is provided, depending on whether one takes an optimistic or pessimistic outlook on the future development of a commercial methanol market. For example, the estimated capital cost of vehicle modifications ranges from \$600 to \$1,500 (Canadian dollars), and annual maintenance costs are estimated at between \$1,500 and \$3,000. For methanol, the cost of the fuel itself represents 75 % of the total costs even under the most optimistic outlook for developing technology. Methanol could compete on a cost basis if diesel fuel prices increased by 75 %. However, no attempt is made to assign monetary value to the air quality benefits associated with methanol use.

Booz, Allen & Hamilton, Inc. 1983. Evaluation of Alternative Fuels for Urban Mass Transit Buses: Final Report. Prepared for U.S. Department of Transportation/UMTA and Port Authority of Allegheny County, Pennsylvania (UMTA-PA-06-0060-83-1).

The objective of this paper is to identify an alternative to the use of diesel fuel in transit buses. The main focus of this analysis of several types of alternative fuels is economic rather than environmental. The impetus behind this project appears to be the great instability of oil prices during the previous decade, and the authors suggest that transit operators should select an alternative fuel conversion approach with low initial costs and the flexibility of converting back to diesel should that fuel become significantly more cost-effective. A number of alternative fuels were ranked by cost, availability, safety and technical feasibility for use in diesel engines with limited modifications. The field was narrowed to six fuels (ammonia, methanol, ethanol, hydrogen, natural gas and propane), all of which were determined to assist in making the transit industry independent from imported crude oil. Several types of engines were also studied, with the ignition-assisted diesel engine identified as the most efficient and versatile. This engine technology was then used to assess fuel cost and suitability factors for the six potential fuels. The selection of the best fuel was based on the costs of the fuel in use and the costs of technology needed to use the fuel. A detailed method is presented for tabulating the presumed 12-year life cycle costs. Methanol is identified as the fuel which best meets the economic and technical feasibility criteria of this study. A detailed demonstration plan is then described to test methanol buses in northern, cold climate cities.

Bush, J. L. 1992. "Natural Gas is Leading Contender for State School Bus Fleets." School Bus Fleet, April/May, pp. 28-36.

This article addresses some of the practical aspects of converting school bus fleets to alternative fuels. The experience of the Tulsa, OK school district with CNG buses is used as an example of what costs, benefits, and potential problems school districts can expect when converting a fleet to CNG. The District reports fuel cost savings between \$800 and \$1,000 per bus based on an average of 15,000



miles annually. Vehicle conversion costs range from \$3,000 to \$3,500, depending upon the number of \$1,000 fuel tanks needed. Refueling compressors range in price from \$47,000 to \$58,000. Overall, the District has few problems to report, although a lack of knowledge was cited as the cause of most problems that have been experienced to date. This article also provides an outline of the companies involved in alternative fuel technology. Tecogen of Waltham, MA currently produces the only California Air Resources Board-certified CNG engine, but Hercules Engine Co. of Canton, OH is also working on a CNG engine which it hopes to certify soon. Detroit Diesel is also developing CNG versions of its DDC 6V-92TA diesel engine. The conversion of school buses to natural gas in the Austin, TX school district is discussed, as an example of the cost effectiveness of retrofitting existing diesel buses rather than purchasing new alternative fuel buses.

Chandler, K. L., T. C. Krenelka and N. D. Malcosky. 1991. CNG Bus Demonstration Program Data Analysis Report. Prepared for U.S. Department of Transportation/UMTA by Battelle, Columbus, Ohio (UMTA-OH-06-0056-91-10).

Two demonstration sites were selected to study the development of the Cummins Engine Company's L10G-240 compressed natural gas (CNG) engine. The first is operated by the Central Ohio Transit Authority and the second is used by the Greater Cleveland Regional Transit Authority. This report covers the period from February 1990 to October 1991. The report contains data collected from the two transit agencies on fuel and oil consumption, unscheduled maintenance and other operating factors. The second bus was also tested at the Transportation Research Center of Ohio in August 1991, and data on fuel economy, acceleration, cornering and noise are included from those tests. In general, the Cummins engine is making rapid progress in reliability, with the latest engine configuration showing substantial improvements. No safety problems or accidents occurred at either demonstration site during the period of study. The track testing showed that the bus was generally close to meeting all criteria established by the first Article Transit Bus Test Plan (UMTA-IT-06-0219-09-1) and widely used White Book specifications for an alternative power plant. Those criteria that were not met were only missed by small margins, and the bus always met each criteria area at least partially. No fundamental reasons were identified why the bus could not meet all First Article criteria with further development expected in the foreseeable future.

Craig, E., S. Unnasch and M. Cramer. 1991. Methanol-Fueled Transit Bus Demonstration, Phase II: Final Report. Prepared for California Energy Commission by Acurex Corporation, Mountain View, California (Acurex Report 90-109-ESD).

In 1982, the California Energy Commission, in conjunction with the Golden Gate Bridge, Highway and Transportation District, began its first heavy-duty methanol demonstration project. The goal of the project was to demonstrate the viability of using 100 percent methanol, or M100, in transit applications. Two buses were used in this project: a two-stroke converted diesel engine from Detroit Diesel, and





a four-stroke converted diesel engine from the German company M.A.N. The buses were placed in revenue service in 1984, following a period of route selection and driver and mechanic training. This report focuses on the last 4-1/2 years of the demonstration, from November 1985 through July 1990. An earlier report entitled "Phase I: Technical Analyses" describes the results from the demonstration's first year. The Final Report includes an operating chronology and a discussion of the buses' time in service, driveability in service, fuel economy data and engine upgrades performed. The maintenance performed on each bus is described, along with a component durability analysis and a summary of the results of an engine teardown in 1988. A detailed cost analysis is presented, and the cost of operating a fleet of methanol buses is estimated based on expected maintenance requirements for commercial methanol buses and fuel economy experience from the demonstration. Finally, the results of two rounds of emissions testing are described, where the methanol buses demonstrated significant improvements in emission levels over their diesel counterparts.

Environmental Protection Agency. 1990a. Analysis of the Economic and Environmental Effects of Compressed Natural Gas as a Vehicle Fuel: Volume II -- Heavy-Duty Vehicles. Office of Mobile Sources, Washington, D.C.

This is one in a series of EPA reports on the environmental and economic impacts of a number of alternative fuels. The report begins with an overview of how compressed natural gas (CNG) has been used in heavy-duty vehicles, and it identifies applications where the most rapid growth of CNG would be possible. One chapter is devoted to CNG engine technology and presents emissions data for CNG heavy-duty engines. Costs associated with CNG are discussed, including vehicle costs, fuel costs, and fueling station and maintenance costs. Finally, the environmental benefits of CNG compared to gasoline and diesel are described, focusing principally on the areas of ozone, air toxics and global warming and showing that CNG has the potential to provide significant emissions benefits, provided the technology experiences a greater degree of optimization than is currently in use. Dual-fuel vehicles are discussed, but when considered from the perspective of clean alternative fuels, dedicated CNG vehicles clearly assume a dominant position. Such vehicles can be optimized to make use of the specific combustion properties of CNG, and thus can potentially produce much greater emission reductions and fuel consumption gains than their dual-fueled counterparts.

Environmental Protection Agency. 1990b. Analysis of the Economic and Environmental Effects of Ethanol as an Automotive Fuel. Office of Mobile Sources, Washington, D. C.

Ethanol has a number of properties which make it a good motor vehicle fuel. Its octane is higher than gasoline, its flammability is lower, and its vapor pressure is much lower, resulting in lower evaporative emissions. Under an expanded ethanol program as considered in this report, the wholesale cost range for ethanol produced from corn is estimated at \$1.00 to \$1.50 per gallon. Clearly, without



some subsidies, ethanol could not compete with gasoline at current or most projected prices. Ethanol-fueled vehicles are expected to emit more ethanol and acetaldehyde than a gasoline-fueled vehicle, but possible counterbalancing effects have not been explored. The impact of ethanol on urban ozone has not yet been adequately studied, but preliminary calculations of the relative reactivity of ethanol emissions suggests equivalent ozone benefits from ethanol and methanol. Ethanol is expected to produce substantial air toxics benefits, but its global warming impact will depend heavily on the efficiency of future ethanol production plants and the efficiency of future corn production (7.4 million BTU of fossil fuels are currently used to grow one acre of corn). An ethanol spill should not be as hazardous as a petroleum spill, since ethanol is inherently water soluble and biodegradable. In the U.S., much more vehicle development has been done for methanol than for ethanol, and one chapter in this report discusses the characteristics of methanol and the degree to which methanol development results are applicable to ethanol in light of their similar engineering properties.

Environmental Protection Agency. 1989. Analysis of the Economic and Environmental Effects of Methanol as an Automotive Fuel. Office of Mobile Sources, Washington, D.C.

One in a series of EPA reports on various types of alternative fuels, this report discusses several economic aspects of methanol use, including the cost of methanol production, overseas transportation and U.S. port costs, and the gasoline-equivalent price of methanol. At the time the report was written, the average cost of gasoline was \$1.12 per gallon. The gasoline-equivalent price per gallon of dual-fueled vehicles (operating on gasoline, methanol or a blend of the two) was projected to be between \$1.05 and \$1.09, while the price for a dedicated methanol vehicle was estimated at \$.85 to \$.88 per gallon. Thus, methanol was seen as an attractive alternative to conventional fuel. As for the ozone benefits of methanol, the volatile organic compound (VOC) emissions from methanol vehicles consist mostly of unburned methanol, which has a reactivity of only one-fifth that of gasoline hydrocarbon emissions. Methanol flexible fuel vehicles are projected to emit at least 30 percent less VOC than typical gasoline vehicles, while optimized, dedicated methanol vehicles may emit 80 percent less VOC. The use of methanol is also expected to have a beneficial impact on air toxics emissions, while the effect of methanol on global warming depends to a large extent on how the methanol is produced.

"Favorable Experiences Reported by Transperth Using Natural Gas for Buses." 1990. Bus Ride, January, pp. 72-4.

The city of Perth in Western Australia is increasingly committed to the use of non-diesel fuels in its transit bus fleet. Because the city is extremely remote and the region has enormous reserves of natural gas, Perth has converted several buses to run on compressed natural gas (CNG) and on liquid petroleum gas (LPG). Thirty more buses are currently being converted to CNG in order to assess all operational aspects before proceeding with a full-scale conversion of the entire



fleet. The project has been quite successful thus far. Drivers like the gas-fueled buses because they accelerate better than standard diesel versions, and patrons approve of the quiet and vibration-free ride. Refueling has been accomplished by unskilled personnel after only brief training, and safety requirements have been readily accommodated without much additional expense. These experiences have been helpful to the Australian federal government, which is now actively promoting the use of CNG buses in other cities.

Francis, G. A. and R. D. King. 1988. Proving Ground Comparison of M.A.N. Methanol and Diesel Transit Buses. Prepared for U.S. Department of Transportation/UMTA by Battelle, Columbus, Ohio (UMTA-IT-06-0322-88-4).

This comparison included cold and warm weather tests of three methanol and three diesel M.A.N. transit buses taken from revenue service at Seattle Metro. The first test was a new driveability test structured to evaluate abnormal responses of bus propulsion systems in a carefully controlled environment. The cold starting characteristics of the methanol engine were very poor during January, and were better but not completely satisfactory during August. There was some hesitation during acceleration of the methanol buses, while the driveability of the diesel buses was almost flawless. The second test was an acceleration test, in which the average times required for the methanol and diesel buses to reach a speed of 50 mph were almost equal. The third test was designed to compare interior and exterior noise of the buses under different operating conditions. The methanol buses had higher average noise levels than the diesel buses in all interior tests and in the exterior idle and pull-away tests. However, the differences were so small that they should not be significant to anyone purchasing transit buses. It must be recognized that these tests compare fully mature diesel technology with emerging methanol technology, so no firm conclusions should be based on these results alone.

Garland Independent School District. 1990. Status Report: Compressed Natural Gas. Garland Independent School District, Garland, Texas.

Recent legislation in the Texas Assembly requires all school districts with more than 50 buses to purchase vehicles capable of operating on some type of alternative fuel. Because more than one-quarter of all proven U.S. natural gas reserves are located in Texas, compressed natural gas (CNG) is the alternative fuel of choice for most Texas school districts. The Garland schools have been operating CNG buses since 1983, and currently have a fleet of 81 such buses. This document presents an overview of their experiences with CNG buses, including the costs of conversion, fuel and maintenance, and the advantages of slow fill stations.



Gerndt, H. and R. Stellmacher. 1989. "Battery Powered Electric Buses." Transportation Planning and Technology, 14:217-25.

This paper describes the current status of battery powered electric buses and reports on the results of a five year demonstration project in Dusseldorf. Seventeen buses were equipped with a lead acid battery permanently mounted in a trailer attached to the rear of the bus. Basic charging is done overnight, with intermediate charging coupling techniques having been tested successfully on three different routes. Despite considerably higher coach weight, energy consumption was reduced by more than 20 percent as compared to diesel buses. The feasible range of operation is a maximum route length of 20 km, with a mean recharging time of 0.8 minutes per travelled route kilometer. Currently, the overall costs of battery buses are twenty-five percent higher than for conventional diesel buses, but the project has succeeded in demonstrating the high reliability and technical feasibility of battery operations. Technology developments, such as more efficient energy storage methods, are expected to narrow the cost gap to the point that such technology will be desirable in energy- and environment-sensitive situations. Development of electric vehicles is fostered by the fact that electric drives are functionally superior to internal combustion engines, and that traction energy electricity in the long run will be more economic and safeguarded with respect to availability than combustion fuels.

Gilbert, A. T. and R. Gunn. 1991. Natural Gas Hybrid Electric Bus. Society of Automotive Engineers, Warrendale, Pennsylvania (SAE 910248).

A joint project of Unique Mobility, Inc. and Ontario Bus Industries, the purpose of the hybrid electric bus project is to prove that a compressed natural gas (CNG) internal combustion engine, augmented by storage batteries to provide peak period power, will produce lower emissions and increased fuel economy than a conventional diesel powered bus. A computer model called the Electric Vehicle Computer Model has been developed to predict engine performance and to select drivetrain components, and was used to select a 7.6 meter bus chassis and a 4.3L V6 internal combustion engine converted to run on CNG for this demonstration project. An Engine Management System controls engine speed and power output with varying load conditions. The bus can operate in typical urban stop and go driving cycles with no decrease in net battery energy. The engine provides steady state power for operation up to 37 mph; for operation above 37 mph, or during acceleration and grade climbing, a portion of the power needed to propel the bus is provided by the storage batteries. Further research on engine emissions is currently underway, but preliminary results indicate that emissions from the demonstration bus are significantly lower than those from conventional diesel buses. At the time of this report, the project was addressing detailed design and construction issues.

Giuliani, C. and M. Murphy. 1991. Status of Particulate Trap Developments Related to the Transit Industry. Prepared for U.S. Department of Transportation/UMTA by Battelle, Columbus, Ohio (UMTA-OH-06-0056-91-6).





The use of diesel-fueled transit buses with particulate emissions control devices is an attractive alternative for achieving the standards set by the Clean Air Act Amendments of 1990. The traps in use have many configurations and are made of ceramic monoliths, ceramic foam, ceramic fibre or metal mesh. The traps must be cleaned frequently to maintain engine efficiency, with the preferred cleaning method being to oxidize the particles using exhaust or auxiliary heat. Fourteen buses with particulate traps were being tested at the time of this report: six in Los Angeles, three in Milwaukee, three in New York and two in Dayton. More significant, 450 diesel buses with traps were ordered for delivery during 1991. Results from emissions tests on these buses vary widely, but all show significant reductions in particulate emissions when traps are used. Tests by EPA in 1990 show that it is possible to reach the emission standards of the Clean Air Act with state of the art engine and trap technology. The major problem affecting the functioning of trap oxidizers in transit buses is ensuring that exhaust temperatures are high enough to incinerate the trapped particles. Exhaust temperatures are a function of engine speed and load, and it is more difficult for a transit bus to maintain high exhaust temperatures than it is for an over-the-road truck. The experiences of a number of transit agencies with particulate traps are discussed, and it is concluded that the transit industry is making good progress in this area. However, a few problems remain to be resolved, including the high cost of system components and the lack of long term data on reliability and maintenance requirements.

Hargreaves, D. 1989. "Propane: Safe, Clean and Affordable." Community Transportation Reporter, March, pp. 11-3.

The author is the general manager of the Manistee County Transportation System in Manistee, Michigan. After learning that Michigan transit operators would be faced with declining financial assistance from the state, this system decided to convert gasoline-powered vehicles to propane motor fuel in order to solve their growing budget problems. In the first year that propane vehicles were in operation, the system saved 22% in operating costs over the previous year. Since 1986, 19 of their 22 vehicles have been propane-powered, and operating costs have remained constant. The advantages this system has recognized include: easier starting in cold weather; consistently lower cost per gallon than gasoline or diesel; naturally higher octane rating; reduced maintenance costs because of propane's clean burning properties; easy conversion process; and much cleaner exhaust, resulting in less downtime for emissions testing.

Harmelink, M. D. and O. M. S. Colavincenzo. 1990. The Development of Natural Gas Buses in Ontario. Ontario Ministry of Transportation. Presented at Globe 90, Vancouver, British Columbia, March 22, 1990.

The province of Ontario initiated a conservation and oil substitution program in 1980, as a result of concern for the environment and for the long-term quality, supply and cost of diesel fuel. This initiative included an alternative fuel technology development program which supported the development and



demonstration of natural gas buses, beginning in 1985 in the town of Hamilton and continuing in Toronto and Mississauga. Originally, six buses were converted to natural gas, each with an estimated range of 250-350 km. A complete fuel economy comparison was performed with a diesel and a natural gas bus. The natural gas vehicle consumed 9% more energy, but the power output was similar (i.e. it climbed hills at the same speed as did the diesel bus). During the first few months of the demonstration the expected fuel economy was achieved; however, in later, colder months, the fuel economy of the natural gas bus deteriorated. This may be attributed to cold weather conditions and/or to operation at non-optimal air-fuel ratios. The three cities currently operate 55 natural gas buses, most with large storage tanks on the roof in order to provide a larger operating range and to insure safer operations, since the tanks are out of the usual impact area in collisions and vapors are most likely to rise away from the passenger compartment. Current areas of investigation include examining the modifications to storage garages which may be necessary for safety.

Hull, R. W. 1987. Environmental Benefits of CNG-Fueled Vehicles. Prepared for the Gas Research Institute by Southwest Research Institute, San Antonio, Texas (Contract No. 5084-251-1101).

The objective of this paper was to identify significant environmental, safety and economic benefits associated with CNG-fueled vehicles, relative to gasoline-, methanol- and diesel-fueled vehicles. The ultimate purpose of this study was to identify opportunities for CNG vehicles to penetrate the fleet vehicle market. A number of research projects and demonstration programs were reviewed. It was concluded that natural gas is a cleaner fuel than either gasoline or diesel, and can be considered as safe or safer than gasoline. These benefits were compared with methanol, another clean-burning alternative fuel, and recommendations were made for future research and development to make CNG a more attractive option for fleet operators, including better engine optimization and onboard fuel storage. Urban transit bus fleets were specifically identified as providing excellent opportunities for expansion of CNG usage, because of the need for transit operators to meet the EPA's stringent emissions standards.

Hundleby, G. E. 1989. Low Emissions Approaches for Heavy-Duty Gas-Powered Urban Vehicles. Society of Automotive Engineers, Warrendale, Pennsylvania (SAE 892134).

Starting from the premise that current diesel technology probably will not be able to meet air quality standards (most notably, the particulate standard), this paper attempts to identify the optimum approaches for achieving low emissions operation with spark ignited natural gas engines. "Low emissions" vehicles are considered to be those that meet the 1994 Federal heavy duty emissions limits. Several operation scenarios are identified and contrasted, including lean burn open loop control versus closed loop mapped control, and no catalyst versus a 2- or 3-way catalyst. It is found that a combination of EGR dilution, advanced control and a 3-way catalyst produces the lowest achievable emission rates. A natural gas bus



project sponsored by a consortium of five major Nordic transportation agencies is currently underway using this combination of technology, and very low emission levels are expected.

Indirect Source Control Committee. 1992. Procedure to Determine Emission Reductions: School Bus Conversion. California Air Pollution Control Officers Association.

This document provides a procedure to calculate potential emission reductions achievable by converting gasoline-powered school buses to compressed natural gas (CNG). This procedure involves four discrete steps: determining the life of the emission source; calculating the baseline emissions over the life of the source; calculating controlled emissions over the life of the source; and calculating net emissions reduction. Emission factors for various pollutants are taken from the California Air Resources Board's EMFAC model. Each step is treated in detail, with equations provided for each calculation and example calculations completed for a hypothetical fleet of 15 buses. Limited data is currently available for emissions deterioration rates of CNG buses, so the deterioration rates are assumed to be the same as for new 1991 gasoline-powered school buses. These rates should be revised as new data becomes available.

Indirect Source Control Committee. 1992. Procedure to Determine Emission Reductions: Transit Bus Replacement. California Air Pollution Control Officers Association.

This document provides a procedure to calculate potential emission reductions associated with replacing diesel powered transit buses with alternatively fueled vehicles. The steps involved in this procedure are the same as those described in "Procedure to Determine Emission Reductions: School Bus Conversion" (cited above), and sample calculations are performed for a hypothetical fleet of 15 buses. Because limited data exists on emissions from various alternative fuels, this procedure assumes that emissions from alternatively fueled buses will be equivalent to emissions from transit buses meeting the 1991 model year emission standards. As more complete data becomes available for specific alternative fuels, that data should be used with this procedure.

Klausmeier, R. F. and J. Draves. 1991. "Assessment of Environmental Issues Related to the Use of Alternative Transportation Fuels -- Analysis of Recent Data." Air & Waste Management Association Annual Meeting, Vancouver, British Columbia (91-106.3).

The emphasis in this paper is on how methanol, compressed natural gas (CNG), liquefied petroleum gas (LPG) and reformulated gasoline compare with gasoline and diesel in the areas of ozone attainment, air toxics and global warming. Both light- and heavy-duty applications of alternative fuels are considered. In general, dedicated CNG vehicles appear to have the greatest ozone benefits, with LPG and methanol vehicles also offering significant benefits. Dual-fuel CNG or LPG



vehicles and M85 (85 % methanol and 15 % gasoline) vehicles may not be much better than gasoline vehicles, because evaporative non-methane organic gas emissions from storage of gasoline greatly increase their overall contribution to ozone formation. Both dedicated and dual-fuel CNG vehicles emit much less CO than gasoline vehicles; LPG also produces a CO benefit. Preliminary data show that both M85 and M100 vehicles emit much more CO than CNG vehicles. CNG vehicles have significantly lower emissions of air toxics than gasoline vehicles. The use of methanol should lower tail pipe emissions of toxic hydrocarbon compounds, but will increase emissions of formaldehyde, a known carcinogen. Little information is available on the impact of LPG on air toxics, but it should result in lower benzene and toluene emissions. Although they may produce more methane, CNG vehicles emit 30 percent less CO<sub>2</sub> than their gasoline counterparts, thereby lowering their overall greenhouse gas emissions. The impact of methanol on global warming depends on how the fuel is produced. Methanol made from natural gas produces 6 percent less greenhouse gas emissions than gasoline vehicles, while methanol made from coal will increase those emissions relative to gasoline.

Krenelka, T. C. and M. J. Murphy. 1990. Methanol Status Report. Prepared for U.S. Department of Transportation/UMTA by Battelle, Columbus, Ohio (UMTA-OH-06-0056-90-2).

This report covers data collected from the beginning of Seattle's methanol demonstration program in 1987 through February 1990, when methanol programs had been added in New York, Denver and Los Angeles. This data base is derived from almost two million miles of revenue operation of methanol demonstration buses. The methanol buses were roughly 18 percent less fuel efficient, on an energy equivalent basis, than their diesel counterparts. The methanol buses required more frequent maintenance and more maintenance labor hours per mile than the diesel buses. However, it should be noted that mechanics are generally highly experienced with diesel buses, and have little methanol bus experience. Two engine problems emerged as significant issues: short glowplug life, which seems to have been solved by changes to the glowplug controller; and plugging of fuel injectors in the Detroit Diesel engines, which is yet to be solved (although this problem did not occur in the M.A.N. engines). No significant safety, health or accident issues arose relating to the use of methanol during the period of this study. Methanol vapor level measurements were made at Seattle Metro and in a maintenance shop in Denver, and the results showed compliance with all pertinent OSHA regulations and other recommended human exposure limits. Methanol buses appear to be well accepted by drivers, mechanics and the general public.

Leonard, J. H. 1989. "Activities of the South Coast Air Quality Management District to Promote Alternatively Fueled Motor Vehicles." Air & Waste Management Association Annual Meeting, Anaheim, California (89-63A.3).

This paper presents an overview of the alternative fuel projects undertaken by the South Coast Air Quality Management District (SCAQMD) as part of its strategy to





achieve the air quality goals set forth in the District's Air Quality Management Plan. Because mobile source control in the South Coast Air Basin is perhaps the nation's most difficult air pollution challenge, SCAQMD is actively promoting the research, development, demonstration and commercialization of alternatively fueled vehicles on many fronts. Several of these projects focus on reducing emissions from transit buses and other heavy-duty vehicles. SCAQMD is cosponsoring a project with ICI to evaluate the technical feasibility and emission benefits of retrofitting diesel buses to operate on methanol, with Avocet as a chemical ignition improver. SCAQMD is also cosponsoring a project to perform a comparative evaluation of clean fuels in transit buses operated by the Orange County Transit District. This project will provide direct comparison data which does not currently exist about different types of alternative fuels. Finally, SCAQMD is involved in a project to develop and demonstrate technology for fuel cell/electric battery-powered urban buses. This technology has the potential to meet the definition of Ultra Low Emitting Vehicles called for in the South Coast's Air Quality Management Plan.

N.B. The annual report for SCAQMD's Technology Advancement Office, which monitors the progress of these projects, is due to be released in late summer or early fall 1992. That report will provide updated information on the status of these programs.

Maggio, M. E., et al. 1991. Challenges for Integration of Alternative Fuels in the Transit Industry. Transportation Research Board, Washington, D.C., Transportation Research Record 1308.

This paper provides some background information on several potential transit fuels, including CNG, methanol, ethanol, LPG and reformulated fuels, and presents an overview of the physical and handling properties, the health hazards, and some of the supply issues related to these fuels. Differences between properties of alternative and conventional fuels, and precautions that should be taken to guard against risks of handling alternative fuels and maintaining alternative-fuel engines, are identified. It is concluded that alternative fuels present different risks than conventional fuels, but those risks are not necessarily greater. The paper also counters some misconceptions about the hazards of integrating alternative fuels into transit fleets. All fuels present significant health and safety challenges, and experience has shown that with proper training, facility design and safety precautions, alternative fuels can be handled safely by operations, service and maintenance personnel.

Mathieson, M. 1991. "Alternative Fuels Applications for School Transportation." National School Bus Report, December, pp. 16-7.

This article briefly discusses the views of Thomas Built Buses, a school bus manufacturing company, on the feasibility of using various alternative fuels in school bus applications. The main focus of the author is on safety, but economic factors in school bus conversions are also discussed. Clean diesel is identified as

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the fuel of choice for this manufacturer, because it is a "familiar" technology that can safely and economically meet government goals of reduced air pollution. However, because emerging catalytic converter and particulate trap technology will likely not be ready for use in time to meet the Clean Air Act's heavy-duty emission reduction goals, Thomas Built is also evaluating other types of alternative fuels. Methanol is not considered an acceptable fuel, due to reported mechanical difficulties and the potential for highly increased aldehyde emissions. Similarly, liquid natural gas (LNG) is classified as an unsuitable school bus fuel for several safety reasons, such as the vulnerability of fuel tanks to accident damage and the propane-like actions of LNG in a leak situation. Compressed natural gas (CNG) is considered an acceptable school bus fuel, and Thomas Built is in the process of constructing a prototype CNG-powered chassis for demonstration purposes. CNG is relatively safe, as long as certain handling procedures are followed, and Thomas Built recommends that CNG be approved for school bus use.

Meloche, M. J. 1990. Summary of Alternative Fuel/Clean Air Technology Buses in North American Transit Use. American Public Transit Association, Washington, D.C.

This document, which is updated periodically, contains a listing of all alternative fuel transit buses in operation in North America as of April 13, 1990. This information is provided by transit professionals and the engine manufacturers. Data listed include the operating agency, installation date, number of buses, engine type, manufacturer, and contact name and telephone number. The types of buses considered to run on "alternative fuels" include battery-powered, methanol, ethanol, diesel with particulate traps, compressed natural gas, liquid natural gas, liquified petroleum gas and trolleybuses.

Mueller Associates, Inc. 1986. Dual-Fuel School Bus Demonstration: Final Report. New York State Energy Research and Development Authority, Albany, New York (Report 87-17).

The overall objective of this project is to demonstrate the technology and economics of using compressed natural gas (CNG) in transportation vehicles; school bus fleets were chosen because of their large fuel use, advantageous usage patterns, and the benefits which would accrue from reduced fuel use. Three New York school districts participated, each converting up to 10 buses to use CNG and allowing data to be collected from a similar number of gasoline and diesel fuel control buses. The project lasted three years, beginning with the '83-'84 school year. Data collected includes bus fuel economy, bus maintenance costs, refueling station operating and maintenance costs, regulatory problems, safety and community acceptance. No safety or community acceptance problems were experienced in any school district. When tuned, the CNG buses performed very well and drivers were happy with the improved driveability. On average, the CNG buses achieved better fuel economy than their gasoline counterparts, though the diesel buses' fuel economy was still the highest because they use much less



fuel at idle than do spark ignition engines. Extended spark plug and oil change intervals were experienced for CNG vehicles, but the project duration was too short to assess the effect of CNG on engine or exhaust system lifetimes. Overall, it appears that CNG fueling stations can be operated by typical maintenance personnel with small amounts of training. Station maintenance does take time, especially during the start-up phase, so it is suggested that fleet operators recognize this and respond by providing additional maintenance personnel to perform the required work. In addition, great emphasis should be placed on vendor quality and reliability. Vendors should provide a strong warranty and an extensive training program. In order to achieve positive annual operating savings, it is estimated that the cost of gasoline should be \$.30/gallon higher and diesel \$.50/gallon higher than the cost of the equivalent amount of natural gas. To be competitive, natural gas must be priced so that when compression and equipment maintenance costs are added in, savings still result. Overall, New York state should benefit from the use of CNG in terms of improved air quality and reduced expenditures for imported petroleum. This report establishes the current (1986) technical and economic status of CNG vehicles, and sets the stage for exploration of optimum, advanced CNG vehicle economics.

Murray, H. S., et al. 1986. DOT Fuel-Cell-Powered Bus Feasibility Study. Prepared for U.S. Department of Transportation by Los Alamos National Laboratory, Los Alamos, New Mexico (LA-10933-MS).

The purpose of this study was to evaluate and document the feasibility of powering standard size and small buses with fuel cells. Specifically, the study objective was to determine whether fuel-cell-powered buses could achieve satisfactory performance on standard drive cycles and whether their life cycle costs could be competitive with conventional diesel buses. The present status of fuel cell systems was documented and expected fuel cell development over the next five years was projected. Preferred propulsion systems consisting of pure fuel cells and fuel cell/battery hybrids were identified. Performance modeling was performed using DOT drive cycles for the standard bus and a Georgetown University route for the small bus. A life cycle cost analysis was performed to determine break-even costs for the fuel cell system compared to conventional diesel-powered buses. It was concluded that a functional, hybrid fuel cell/battery powered bus can be built with currently available technology to meet the requirements of the reduced power DOT drive cycle and, with some lowered top speeds, to meet the Georgetown University route requirements. To break even with a diesel bus, fuel cell and reformer costs should be in the range of \$200 to \$500 per kilowatt. Estimates for fuel cells in electric utility applications were \$1000/kW, but in mass production the \$200-\$500/kW cost may well be achievable. No dollar value was placed on the fuel cell's low air and noise pollution impacts.

O'Connor, M. 1991. Status Report on the Riverside Transit Agency Methanol Bus Fleet. California Air Resources Board, El Monte, California.



Since 1987, the Riverside (CA) Transit Agency (RTA) has been conducting a demonstration program to assess the ability of methanol-fueled buses to operate reliably and achieve very low emission levels. The RTA fleet consists of three GM buses with Detroit Diesel engines converted to operate on neat methanol, and three diesel control buses. The methanol buses initially experienced mechanical problems, including loss of power due to problems with the engine control system and low engine compression. Detroit Diesel (DDC) rebuilt the engines and upgraded the engine control systems. Recent efforts by DDC have significantly improved fuel injector durability and glow plug life, two major maintenance problems experienced by RTA. The methanol buses have undergone four separate emission testing procedures at the Air Resources Board's emission laboratory. It was found that hydrocarbon and carbon monoxide emissions were higher in the methanol buses than in the diesel, but particulate and nitrogen oxides emissions were much lower. These findings are consistent with previous tests of this type of methanol engine.

Reese, J. J. et al. 1992. Comparative Evaluation of Clean Fuels. Prepared for Orange County Transit District by Acurex Environmental Corporation, Mountain View, California (Monthly Progress Report 6590-25).

The Orange County Transit District is evaluating the feasibility of using clean fueled buses and other vehicles in transit service. Eight buses are currently being evaluated: two each of methanol, compressed natural gas (CNG) and propane (LPG) and two diesel control buses. These buses were placed in service in August 1990, and they continue to serve a central business district route. This monthly report covers activity during the month of February, 1992. Included in the report are data on mileage accumulation, fuel economy, road calls and maintenance labor hours, cost of replacement parts and fuel-related costs. The diesel buses experience better fuel economy and lower energy consumption than their clean fuel counterparts, and road calls are less frequent for the diesel buses. Of the clean fuel buses, the methanol vehicles required the fewest maintenance labor hours, although the cost of replacement parts for the methanol buses was much higher than for the others. Acurex is working on scheduling emissions tests for the buses, and plans to start testing by June 1992.

Regional Transportation District. 1992a. Compressed Natural Gas Program, Monthly Report, April, 1992. Regional Transportation District, Denver, Colorado.

In 1990, Denver's Regional Transportation District converted five diesel buses to operate on a combination of diesel and compressed natural gas (CNG). Five diesel buses were used as controls. No routine maintenance procedures have yet been established for the CNG buses, but that is expected soon. Several maintenance problems have been experienced with the CNG buses, including hard starting in cold weather, electronic control problems and defective gas injector valves. Recent emission tests show that the buses will not meet EPA urban bus engine emission standards, but the manufacturer is making significant improvements in the electronic control program and engine calibration which will





hopefully allow the engine to be certified later this year. During the month covered by this report, the CNG buses experienced eight engine/fuel related problems, while the diesel buses had one such problem. The CNG buses averaged 3.13 mpg during the month, using 53% CNG and 47% diesel. The diesel control buses averaged 3.6 mpg. The total operating costs per mile were \$.80 for the methanol buses and \$.42 for the diesel buses.

Regional Transportation District. 1992b. Methanol Program, Monthly Report, March 1992. Regional Transportation District, Denver, Colorado.

Denver's Regional Transportation District is conducting an alternative fuels research program in which five methanol buses were purchased and put in revenue service in 1989. Five diesel buses serve as the control group for this experiment. The methanol and diesel buses operate on the same routes and are exposed to similar schedule speeds, stops per mile and passenger loading. During the month covered by this report, the methanol buses experienced four engine/fuel system problems while the diesel buses experienced three such problems. Average fuel consumption for the methanol buses was 1.61 mpg, with the diesel buses recording an average of 3.53 mpg. The fuel and maintenance costs for the methanol buses were twice as much as for the diesel buses, which is due in large part to much higher fuel costs for methanol. This document contains graphical representations of the preceding data, as well as spreadsheets which provide a breakdown of fuel and maintenance costs for the program over the previous twelve months.

R.F. Webb Corporation, Ltd. 1990. Chapter on Energy, Canadian Transit Handbook. Prepared for Transport Canada.

Diesel fuel dominates the Canadian transit fuel market, but transit systems and other petroleum product users are increasingly concerned about the stability of the oil supply worldwide, as well as about selecting fuel and bus designs to meet rapidly emerging and stringent environmental performance standards. This portion of the Canadian Transit Handbook addresses issues of energy consumption and conservation in the public transit sector, and a large section of the chapter is devoted to an exploration of the role that alternative transportation fuels may play in future Canadian transit decisions. This chapter focuses on the alternative fuels CNG, propane and methanol, both because of their emissions performance and because there can almost certainly be an uninterrupted supply of these fuels from massive Canadian sources. Canada is currently a world-scale exporter of natural gas and methanol, and has demonstrated the feasibility of alternatively fueled buses by accumulating many bus years of revenue service using such fuels in several transit locations. However, the economics of large-scale conversions of transit buses to alternative fuels will be favorable only when benefit calculations include social benefits such as emissions reductions and energy security. Propane and CNG have begun to penetrate the market for light-duty vehicles, and so far several Canadian transit agencies have taken part in alternative fuel demonstration programs, which are briefly described in this chapter. The lowest cost option



currently appears to be propane, due to low fuel cost and relatively low cost for refueling system installation. CNG is attractive for its emission benefits, but the cost of installing a CNG fueling system may confine the use of this fuel to those locations where subsidies can offset the initial costs. Methanol is appealing because it can be handled much like gasoline or diesel, but the disadvantages include relatively high fuel costs, toxicity and high levels of formaldehyde emissions.

Santini, D. J. and J. B. Rajan. 1990. Comparison of Emissions of Transit Buses Using Methanol and Diesel Fuel. Transportation Research Board, Washington, D.C., Transportation Research Record 1255.

The results of several studies on the emission characteristics of methanol- and diesel-fueled buses are summarized. To facilitate comparison, the emissions test data at idle and in various driving cycles are presented on an hourly or per-mile basis. The emissions of specific pollutants from methanol-fueled test vehicles varied greatly with average speed and depended on the engine technology and the emission control devices used. The results suggest that the substitution of methanol-fueled buses for diesel-fueled buses is not likely to result in net air quality improvements for very low speed bus operations in urban environments. In many instances, emission reductions experienced with methanol buses occur only at steady-state cruising speeds, not at idling speeds more common for city transit buses. Under these conditions, the negative effects of increases in CO, formaldehyde, and hydrocarbons may offset the positive effects of particulate reduction. In addition, catalysts in methanol-fueled buses must be maintained scrupulously in order to provide the emission reductions expected. In this paper, no attempt is made to weight emissions, estimate air quality, or quantify net emissions effects.

Santini, D. J. 1988. "Environmental Quality Changes Arising from the Replacement of Diesel Oil-Fueled Buses by Methanol-Fueled Buses." FISITA Conference, Washington, D.C., September 30, 1988 (885168).

A number of issues related to diesel and methanol buses are explored, with the goal of summarizing the considerations that a transit operator and a metropolitan area should include when making decisions about purchasing methanol-fueled buses. Topics covered include: occupational exposures of maintenance workers; probable levels of urban-resident pollutant exposure; environmental consequences of fuel leaks and spills; and air quality effects of in-use emissions. Previous cost/benefit comparisons are analyzed in light of these issues, to determine what the ratios of methanol and diesel fuel prices should be to make adoption of methanol buses desirable. Presumed environmental advantages of methanol engines, which have been estimated based on average driving cycles, are not likely to be as great in heavy, slow traffic. Still, substituting new methanol engines for old diesel engines will precipitate drops in NO<sub>x</sub> and particulate emissions and, if a catalyst were used in the methanol engine, reductions in CO and HC as well. Several characteristics of methanol make changes in operating



and handling practices necessary. Methanol is poisonous and colorless, is more chemically reactive than diesel or gasoline, and has higher volatility and a wider range of ignition temperatures than diesel. It is not more hazardous than gasoline, but requires different precautions in handling. It is preferable to do all methanol refueling outside the garage and to improve ventilation in maintenance pits, because methanol is denser than air and vapors tend to accumulate near the floor. Spill handling for methanol is similar to that for gasoline. Negative effects of introducing methanol buses include reduced safety relative to diesel buses and increased emissions of aldehydes and unburned methanol. However, with proper steps to counteract these effects, the net environmental impact should be positive.

Schleyer, C. H. and W. J. Koehl. 1990. Comparison of Gasoline and Methanol Vehicle Emissions Using VOC Reactivity. Society of Automotive Engineers, Warrendale, Pennsylvania (SAE 902095).

A major air quality benefit attributed to methanol as a motor vehicle fuel is a reduction in ozone concentrations in urban areas. This paper explores the mass, composition and ozone reactivity of the emissions from gasoline and methanol vehicles. Methanol vehicle emission performance based on mass emission rates relative to gasoline is evaluated. The emissions from gasoline and methanol vehicles are then compared by two methods, using a published reactivity scale and an ozone air quality model. This analysis shows no significant difference in the amount of VOC and other pollutants emitted by gasoline and methanol vehicles. The ranges of reactivity for gasoline and methanol overlap, with methanol reactivity the same or higher than gasoline reactivity when equivalent vehicles are compared. In addition, the reactivity scales are compared with each other and with the OZIPM computer model, with varying degrees of agreement. The paper concludes that more work is needed to accurately evaluate measures of photochemical reactivity.

Schmidtke, G. 1989. "Natural Gas Saves District Money on its Bus Fleet." School Bus Fleet, August/September, pp. 61-3.

Since 1984, the Yelm School District in rural Washington state has converted eleven buses to run on compressed natural gas (CNG), at a total cost of \$70,000. After five years, the savings in fuel costs (up to \$1,000 per bus per year) have more than paid for the initial expenditure. In addition, the oil change interval has been doubled and analysis shows that engine wear is significantly reduced with CNG use, thus reducing maintenance costs. CNG was chosen over diesel and propane for several reasons; availability of the fuel, ease of choosing a dual-fuel system, safety considerations and the reduced need for environmentally sensitive underground storage tanks.

Small, K. A. 1989. Methanol Fuel for Los Angeles Area Transit Buses: Costs and Benefits. Institute of Transportation Studies, University of California, Irvine (UCI-ITS-RR-89-1).



This project focuses primarily on the air pollution benefits of converting transit buses to methanol fuel, using two different methods: cost/benefit analysis and cost-effectiveness analysis. The cost/benefit analysis compares the cost of converting the fleet and using methanol with the measurable health benefits from reducing particulates and sulfur oxides. The costs were assessed over a range of possible methanol prices. The results indicate that over a wide range of methanol prices, benefits exceed costs, even though many benefits are omitted in this somewhat narrow calculation. The cost-effectiveness analysis adds a number of factors to the previous work. The clean-air potential of methanol is compared with that of other strategies for reducing diesel emissions, and the comparisons are made for three different pollution indices, each combining the effects of particulates and sulfur oxides in a different way. In all, methanol conversion has a higher cost per unit reduction in pollution than the other strategies. However, it also produces a higher absolute reduction in pollution, thus requiring an examination of the incremental cost of the additional reduction it brings about. In addition, an analysis of energy supply suggests that the ability to rapidly convert a substantial amount of the nation's fuel use to methanol could serve as an important deterrent to a repeat of the oil price increases of the 1970s.

Small, K. A. 1988. Reducing Transit-Bus Emissions: Comparative Costs and Benefits of Methanol, Particulate Traps, and Fuel Modification. Institute of Transportation Studies, University of California, Irvine (UCI-ITS-WP-88-1).

This paper investigates the cost-effectiveness of three strategies for reducing particulate and sulfur-oxide emissions from diesel transit buses, including low-aromatic fuel, particulate traps and methanol. Three alternate indices of emissions are considered: one equal to total particulates (including those formed in the atmosphere from emitted sulfur dioxide); one based on California's ambient air-quality standards; and one based on statistically estimated effects on mortality. At the fuel prices considered most likely, methanol is far more costly than other strategies per unit reduction in total particulates. No seriously proposed estimate of benefits would justify the incremental cost of \$108 per kilogram of particulates reduced by switching from particulate traps to methanol. However, the picture changes when sulfur is taken into account. The incremental cost of using methanol to reduce noxious sulfur emissions by the equivalent of one kilogram of particulates is either \$43 or \$7.50, depending on which of two estimates of sulfur's noxiousness one accepts. In addition, methanol achieves the greatest absolute emissions reduction. Lowering the aromatic content of diesel has promise for achieving modest reductions in particulates, especially since it includes the possibility of immediate application to the entire vehicle fleet without waiting for old vehicles to be replaced.

Southern California Rapid Transit District. 1992. Alternate Fuels Section Quarterly Status Report. October-December 1991, Vol. 2, No. 3.

The Southern California Rapid Transit District has been actively testing and developing clean air technologies which will be applicable to transit service in Los





Angeles in the twenty-first century. Currently the methanol technology is the most mature, and the District has decided to purchase over 300 methanol buses for revenue service in late 1992. Compressed natural gas (CNG) and particulate trap technologies are still being developed, and the District is also exploring electric trolley and liquified natural gas technologies in order to comply with the region's Air Quality Management Plan goals of 30 percent electric and 70 percent alternative fueled urban transit vehicles by the year 2010. The District has developed a cost model to monitor trends in fuel price and operational costs, which will provide the District with information on the developmental process of each technology and how it has been affected by (or has affected) the larger market forces in the energy and transportation industries. This report specifically discusses the operations of the District's various alternatively fueled buses during the fourth quarter of 1991, providing data on fuel economy and maintenance requirements. The report also summarizes project developments during the quarter, and discusses the durability study currently underway to measure the wear on engine components from the use of various types of fuels.

Sypher: Mueller International, Inc. 1990. Project MILE Report: A Report on the Use of Methanol in Large Engines in Canada. Prepared for Energy, Mines and Resources, Canada.

Project MILE (Methanol in Large Engines) was initiated in 1984 by Canada's federal Department of Energy, Mines and Resources. It was intended as a long-term trial of methanol-fueled compression ignition engines in trucks and buses. Demonstration buses were included in the fleets of Winnipeg and Medicine Hat. Each fleet had custom-built fueling stations, safety equipment, personnel training and repair and service backup for support. By October, 1989, the demonstration vehicles had covered almost one million km in revenue service. Problems with engine reliability were experienced, but continuing developments by the manufacturers significantly improved the mechanical operations of the buses. The methanol buses eventually matched diesel buses in power, driveability and monthly availability. Fuel consumption on an energy content basis did not equal that of diesel. Some mechanical problems remain, such as fuel injector tip blockage, glow plug durability and valve seat wear. However, it was found that methanol buses can be operated with little disruption to normal servicing and operating procedures. Methanol fueling could not compete economically with diesel. However, large reductions in methanol production costs coupled with increased prices for diesel engines and fuel due to more stringent emissions standards could make methanol more cost effective in the future. This project indicated that methanol is currently technically feasible as an alternative fuel, and significant emission reductions are possible with its use. The demonstration was so successful that the city of Medicine Hat plans to convert its entire transit fleet to methanol.

Tulsa Public Schools Transportation Department. 1992. Compressed Natural Gas Information Fact Sheet. Tulsa Public Schools, Tulsa, Oklahoma.



This informal document outlines the Tulsa Public School District's experience with school buses converted to run on compressed natural gas (CNG). The District entered a pilot program financed by the state of Oklahoma in 1988, to test the feasibility of operating a fleet of CNG vehicles. The Tulsa Schools now operate 102 CNG buses, the largest such fleet in the nation. Of those buses, 67 have dual-fuel systems and 45 have dedicated CNG engines. The District experiences fuel cost savings of between \$800 and \$1,000 per bus per year, as well as maintenance cost savings due to less frequent oil changes and routine tune-ups. The document includes information on fill station construction, fuel mileage and mileage range, safety and fueling requirements, as well as a list of vendors involved in the implementation of the CNG program.

Unnasch, S. et al. 1990. Transit Bus Operation with a DDC 6V-92TAC Engine Operating on Ignition-Improved Methanol. Society of Automotive Engineers, Warrendale, Pennsylvania (SAE 902161).

This paper describes the steps taken to retrofit three diesel-powered buses to run on methanol. The buses are currently in use in the Southern California Rapid Transit District in Los Angeles. The existing engine is modified by installing higher compression ratio pistons and higher flowrate mechanical fuel injectors, while the fuel system is altered to accommodate the properties of methanol. An existing underground storage tank formerly used for leaded gasoline is converted for methanol use. Different types of fuel pumps are described, as well as the fuel supply and delivery system in the Southern California region. The operating experience with the buses is fully discussed, including routes and schedules, the training of drivers and maintenance workers, average fuel economy, engine and component durability and operating costs. In general, methanol bus performance compares favorably with diesel, although methanol buses consume about 2.5 times as much fuel. The cost of methanol, therefore, remains an important concern as this demonstration project continues.

Unnasch, S. et al. 1986. Emission Control Options for Heavy-Duty Engines. Society of Automotive Engineers, Warrendale, Pennsylvania (SAE 861111).

While diesel is the fuel of choice for most transit buses and other heavy-duty applications, environmental concerns about particulate and NO<sub>x</sub> emissions from diesel combustion are causing diesel manufacturers and operators to look for effective control techniques. Controlling particulates without increasing NO<sub>x</sub> has been difficult with combustion modifications alone. This paper evaluates practical measures which can meet both the particulate and NO<sub>x</sub> standards, including particulate traps, clean (low sulfur, low aromatics) diesel fuel, gasoline and methanol. Measures are evaluated not only on the emissions reductions they can produce but also on their incremental life cycle costs. In terms of total cost, a long-life particulate trap that does not require premium fuel has the lowest incremental cost impact. If a trap does require premium fuel or does not reach its target life expectancy, all the approaches have approximately the same cost impact. However, in terms of overall air pollution control strategies, methanol



gains an advantage because it produces more benefits than particulate reduction alone. Methanol shows good cost effectiveness when air quality goals include substantial reductions in both particulates and NO<sub>x</sub>.

Wachter, W. F. 1990. Analysis of Transient Emission Data of a Modelyear 1991 Heavy Duty Diesel Engine. Society of Automotive Engineers, Warrendale, Pennsylvania (SAE 900443).

U.S. heavy duty emission standards are expected to force huge efforts in engine design and production. In response, a research program was undertaken to identify phases of the heavy duty diesel transient cycle (HDDTC) with the most potential to reduce emissions. For each controlled pollutant, the researchers identify the phases of the HDDTC where significant contributions to overall emission were made. In addition, the effects of various operating conditions, such as combustion system configuration and quality of lube oil and diesel fuel, are quantified and analyzed, and suggestions are made as to the conditions most suitable for optimum emission reduction. A warning is given that, although the 1994 limits can be met with a laboratory engine under certain conditions, production scatter and deterioration of emissions over the life of the engine are factors of great importance in the estimation of actual emissions, and are not yet fully understood by manufacturers.

Zelenka, P. et al. 1990. Ways Toward the Clean Heavy-Duty Diesel. Society of Automotive Engineers, Warrendale, Pennsylvania (SAE 900602).

A review of the current development of heavy-duty diesel engines is followed by a discussion of the technologies necessary to meet the U.S. 1994 heavy-duty emissions standards. One promising development is the application of an oxidation catalyst as an efficient and cost-effective device for burning off such pollutants as CO, HC, PAH and soluble particulates. Other benefits of the oxidation catalyst include significant reduction of aldehydes, reduced system cost and complexity, and a levelling of the usual production variability of hydrocarbon-related emissions. However, the catalyst is only a feasible solution of low-sulfur fuel is readily available. Challenges to reducing emissions even further after 1994 are discussed, with emphasis on the future development of a methanol diesel engine for achieving greater NO<sub>x</sub> reductions.



Table 1. Summary Observations on Alternately Fueled Buses

FUEL	COST	BENEFITS	LIABILITIES	EMISSIONS IMPACTS
<p>Methanol (neat and/or FFV)</p>	<p>Bus Purchase: \$230,000 (compared with \$213,000 for equivalent diesel)</p> <p>Fuel Cost (cents/mi): 34.1 (24.3 for diesel)</p> <p>Total Cost (cents/mi): 136- 146 (118.6 for diesel)</p> <p>(From Craig et al., 1991)</p> <p>(Small, 1988) notes that fuel cost for methanol vehicles was 56% greater than diesel.</p> <p>(Bol et al., 1989) states that the cost of the fuel itself represents up to 75% of the total cost of the technology.</p>	<p>Well accepted by drivers, mechanics, and the general public (Krenelka et al., 1990)</p> <p>Only alternative technology to meet 1991 transit emission standards (Maggio et al., 1991)</p> <p>Future modifications could increase cost-effectiveness and reliability (Sypher:Mueller International, 1990)</p> <p>Methanol can be produced using excess natural gas from by petroleum refining operations; this gas is currently vented or burned off as a flare (EPA, 1989)</p>	<p>Poor cold-start performance (Klausmeier et al., 1991)</p> <p>Require more maintenance than diesel vehicles</p> <p>18% less fuel-efficient (Krenelka et al., 1990)</p> <p>Highly corrosive, toxic; risk of explosion on impact (Maggio et al., 1991)</p>	<p>Lower toxic hydrocarbon emissions than diesel or gasoline.</p> <p>On a reactivity-equivalent basis, methanol FFVs are projected to emit at least 30% less VOCs; dedicated methanol vehicles could reduce VOC emissions by at least 80%.</p> <p>When produced using natural gas, methanol produces 6% fewer greenhouse gas emissions (coal-produced methanol increases greenhouse gas emissions) (Klausmeier et al., 1991).</p> <p>Lower particulate and NO<sub>x</sub> emissions, higher HC and CO emissions are expected (O'Connor, 1991).</p> <p>Higher HC and CO emissions from methanol can be reduced using a catalyst (Santini, 1988).</p> <p>Prototype methanol vehicles have been shown to have formaldehyde emissions than gasoline, but this can be reduced by using catalytic converters (EPA, 1990).</p>





Table 1. continued.

FUEL	COST	BENEFITS	LIABILITIES	EMISSIONS IMPACTS
Ethanol (neat/nearly neat)	<p><b>*E85 (85% ethanol blend):</b> \$1.27 - 1.89 per gallon (compared to gasoline from high crude at \$1.07/gal); these are FFVs which represent only a 2.5% efficiency improvement over gasoline.</p> <p><b>E100 (100% ethanol):</b> \$0.99 - 1.59 per gallon, with 30% better efficiency than a gasoline-powered engine (\$1.07/gal for gasoline) assuming a dedicated ethanol vehicle.</p> <p>* Cost comparisons assume a \$1.00 - 1.50 gate price and a 60 cent/gal blending tax credit.  (EPA, 1990)</p>	<p>Ethanol can be produced domestically, decreasing demand for foreign oil and improving the overall U.S. economy.</p> <p>Spills of ethanol are potentially less hazardous than gasoline/diesel because of its limited toxicity, biodegradability, and water solubility. (Maggio et al., 1991)</p> <p>Ethanol can be produced from a variety of sources, including corn, sugar cane, wine, and other biomass. It is the only non-fossil, and consequently renewable, fuel in commercial use (EPA, 1990).</p>	<p>More explosive than gasoline; must be stored in specially vented containers.</p> <p>While current supplies of ethanol are large, it is estimated that doubling the U.S. ethanol capacity would overwhelm the agricultural sector, creating the need for imports. (Maggio et al., 1991)</p> <p>Increased demand for ethanol could have negative effects on the agricultural side due to potential soil erosion and increased water and pesticide use.</p> <p>Tax credits ethanol producers would decrease revenues to the U.S. general fund, requiring increased taxes in other areas to compensate for the shortfall.</p> <p>Although ethanol burns more cleanly than fossil fuels, it currently requires about 7.4 million BTU of fossil fuels to produce one acre of corn to make ethanol. (EPA, 1990)</p>	<p>Dedicated ethanol vehicles emit little or no benzene, and blended fuels using ethanol exhibit decreased benzene emissions.</p> <p>It is probable that neat ethanol vehicles could be engineered to have only 10% of the carcinogen emissions as gasoline vehicles.</p> <p>Air quality effects of optimized ethanol vehicles are expected to be in the area of ozone and air toxics emissions reductions.</p> <p>Efficiency improvements in ethanol production facilities could achieve a 21-22% CO<sub>2</sub> benefit.</p> <p><b>Net CO<sub>2</sub> Emissions Comparison:</b> Gasoline = 371 g/mi E85 = 350-353 g/mi E100 = 290-291 g/mi (EPA, 1990)</p>



Table 1. concluded.

FUEL	COST	BENEFITS	LIABILITIES	EMISSIONS IMPACTS
<p>Compressed Natural Gas (CNG)</p>	<p><b>Energy Equivalent Price Comparison:</b></p> <p>Gasoline = \$1.08 per gallon  CNG = \$0.71 - 1.20 per gallon</p> <p>Diesel = \$0.95 per gallon  CNG = \$0.79 - 1.35 per gallon</p> <p>(EPA, 1990)</p>	<p>Because of its wide residential and commercial use, there are distributions systems and a supply network already in place. This distribution network is currently superior to that of all other alternative fuels, but would need to be improved and expanded with increased motor vehicle use (e.g. there are currently 250-300 CNG refueling facilities in the U.S., 16 of which are public-access).</p> <p>CNG has been used in vehicles since the 1960s; this means that mechanics and operators are accustomed to its properties and risks.</p> <p>(Maggio et al., 1991)</p> <p>A current stoichiometric CNG engine uses almost 11 % less energy than its gasoline counterpart, while an optimized CNG engine uses 15 % less energy than a gasoline engine (EPA, 1990)</p>	<p>The requirement to generate enough energy per volume of storage requires a high level of compression. This requires a great deal of gas, high-voltage compressors, and bulky vehicle tanks.</p> <p>Higher heat from ignition presents problems in heat dissipation from CNG-powered HDVs. (Maggio et al., 1991).</p> <p>Putting enough storage capacity on a CNG for it to have equivalent range of a gasoline or diesel vehicle increase vehicle weight 6.5-9.4 %. In transit buses increased weight may result in a de-rating of the passenger carrying capacity (EPA, 1990).</p>	<p>CNG can "significantly reduce hydrocarbon, NO<sub>x</sub>, and CO levels from diesel levels."</p> <p>CO emissions from CNG vehicles are more than 50 % below those of gasoline engines.</p> <p>CNG engines emit no PM; however, it is difficult for them to meet NO<sub>x</sub> emission standards.</p> <p>(Maggio et al., 1991)</p> <p>It is predicted that future development of the technology will result in reductions in HC and CO emissions, although this same optimization could result in increased NO<sub>x</sub> emissions (EPA, 1990).</p>



TABLE 2

# AMERICAN PUBLIC TRANSIT ASSOCIATION Summary of Alternative Fuel/Clean Air Technology Buses in North American Transit Use

## COMPRESSED NATURAL GAS (CNG)

Transit System/City	Installation Date	New/Repower	Engine	Fuel	Contact Name and #	# of Units	Manufacturer
Command Bus Brooklyn, NY	7/88 10/90	New Repower	Chev 454 L-10	CNG	R. Drager (718) 403-3011	2	Bus Industries of America
Cleveland RTA Cleveland, OH	2/90	New	L-10	CNG	J. Bartkiewicz (216) 421-1005	1	Flible
Central Ohio Transit Authority Columbus, OH	3/90	New	L-10	CNG	G. Schmauch (614) 275-5800	1	Flible
Dallas Area Rapid Transit Dallas, TX	In Production	New	L-10	CNG	S. Cox (214) 748-3278	2	Flible
Regional Transportation District Denver, CO	In Production	New	Ford 460	CNG	Tony Cooper (303) 572-4928	5	Stewart & Stevenson
Fort Worth Transportation Authority Fort Worth, TX	In Production	New	L-10	CNG	D. Harris (817) 870-6221	3	Flible
Hamilton, ON	2nd QTR '91	New	L-10	CNG	R. Duncan (416) 528-4200	15	Bus Industries of America
Metropolitan Transit Authority of Harris County Houston, TX	10/90	New	Ford 460	CNG	Russ Pentz (713) 635-0237	6	Stewart & Stevenson
S.C.R.T.D. Los Angeles, CA	In Production 1 Delivered 12/89	New	L-10	CNG	M. Marcus (213) 972-5894	10	Flible
New Jersey Transit Maplewood, N.J.	4/91	New	L-10	CNG	B. Betz (201) 373-6300	5	Flible
Mississauga Transit Mississauga, ON	5/89 Second Half 1991	Repower New	L-10 L-10	CNG	A. Gillis (416) 393-3294	1 10	Bus Industries of America
Orange County Transit Orange County, CA	4/1/90	New	L-10	CNG	E. Medelin (714) 638-9250	2	Gillig
Tri-County Metropolitan Transportation District of Oregon Portland, OR	1st QTR '91	New	L-10	CNG	M. Grove (503) 238-4915	2	Gillig

Source: Summary of Alternative Fuel/Clean Air Technology Buses in North American Transit Use." M. J. Meloche, 1990



TABLE 2 (continued)

Transit System/City	Installation Date	New/Repower	Engine	Fuel	Contact Name and #	# of Units	Manufacturer
Pittsburgh, PA	2/91	New	L-10	CNG	T. Rochon (412) 237-7000	5	Bus Industries of America
Salt Lake City, UT	2nd QTR '91	New	L-10	CNG	J. Ercanbrack (801) 262-5626	5	Bus Industries of America
North San Diego County Transit District San Diego, CA	2nd QTR '91	New	L-10	CNG	R. L. Fifer (619) 967-2828	1	Flexible
Pierce Transit Tacoma, WA	1985 2nd QTR '91	Repower New	6V-71 L-10	Diesel/CNG CNG	Ron Shipley (206) 581-8080	2 15	GMC New Look Bus Industries of America
Pierce Transit Tacoma, WA	Nov/Dec '90	New	Ford 460 EFT 460	CNG	Ron Shipley (206) 581-8080	19	El Dorado
Toronto Transit Commission Toronto, ON	7/89 Ongoing	New	L-10	CNG	P. Krong (416) 393-3294	27	Bus Industries of America

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TABLE 2 (continued)

# AMERICAN PUBLIC TRANSIT ASSOCIATION

## Summary of Alternative Fuel/Clean Air Technology Buses in North American Transit Use

### DIESEL WITH PARTICULATE TRAPS

Transit System/City	Installation Date	New/Repower	Engine	Fuel	Contact Name and #	# of Units	Manufacturer
Massachusetts Bay Transportation Authority Boston, MA	6/90	Repower	6V-92TA	Diesel	E. Dunn (617) 722-5491	1 (4)	Transportation Manufacturing Company
New York City Transit Authority Brooklyn, NY	1989, 1989, 2nd QTR 1990, Planned 11/90	Repower, Repower, Repower, New	6V-92TA	Diesel	J. Walsh (718) 240-3116	3(1) 1(2) 1(3) 400	Transportation Manufacturing Company
Dayton Transit Dayton, OH	1/91	New	6V-92T	Diesel	Jim Adams (513) 226-1333	25 (2)	Transportation Manufacturing Company
Dayton Transit Dayton, OH	Late 4/90	New	6V-92TA	Diesel	Jim Adams (513) 226-1333	2 (2)	Transportation Manufacturing Company
Regional Transportation District Denver, CO	In Production	Repower	6V-92T	Diesel	Bob Reposa (303) 572-4930	5	Neoplan
Southern California Rapid Transit District Los Angeles, CA	1 Unit 1/90, Rest 6/90, After 6/90	Repower Repower	6V-92TA	Diesel Diesel	V. Pellegrin (213) 972-5844	11 (2) 10 (2)	Transportation Manufacturing Company Neoplan
Milwaukee County Transit Milwaukee, WI	2/90	Repower	L-10	Diesel	D. Harvey (414) 937-3283	1 (5)	Neoplan
Southeastern Pennsylvania Transit Authority Philadelphia, PA	4/90	Repower	6V-92TA	Diesel	B. Vermeychuck (215) 456-5150	1 (4)	Neoplan

- (1) CATALYZED DIESEL BURNER BY-PASS TRAPS (ORTECH)
- (2) DUAL ELECTRIC TRAPS (DONALDSON)
- (3) NON-CATALYZED DIESEL BURNER, FULL-FLOW TRAP (DONALDSON)
- (4) 3M CERAMIC FIBER, ELECTRIC REGENERATION TRAP
- (5) CUMMINS DESIGNED TRAP

Source: "Summary of Alternative Fuel/Clean Air Technology Buses in North American Transit Use." M. J. Meloche, 1990



TABLE 2 (continued)

## AMERICAN PUBLIC TRANSIT ASSOCIATION

## Summary of Alternative Fuel/Clean Air Technology Buses in North American Transit Use

## METHANOL

Transit System/City	Installation Date	New/Repower	Engine	Fuel	Contract Name and #	# of Units	Manufacturer
Niagara Frontier Transportation Authority Buffalo, NY	10/89	New	6V-92	Methanol/Avocet	K. Newman (716) 855-7224	2	Bus Industries of America
Denver RTD Denver, CO	4/89	New	6V-92T	Methanol	L. Luttrell (303) 573-4059	5	Transportation Manufacturing Company
Triboro Coach Jackson Heights, NY	11/87	Repower	6V-92T	Methanol	J. Kimmel (718) 335-1000	6	General Motors RTS
Southern California Rapid Transit District Los Angeles, CA	5/89	Repower	6V-92	Methanol/Avocet	V. Pellegrin (213) 972-6000	12	Transportation Manufacturing Company
Southern California Rapid Transit District Los Angeles, CA	6/89 - 12/89	New	6V-92T	Methanol	V. Pellegrin (213) 972-6000	30	Transportation Manufacturing Company
Southern California Rapid Transit District Los Angeles, CA	6/89 - 12/89	New	6V-92T	Methanol/Avocet	R. Davis or V. Pellegrin (213) 972-6000	12	Transportation Manufacturing Company
Medicine Hat Transit Medicine Hat, Manitoba	1/87	Repower	6V-92T	Methanol	D. Gaze (403) 529-8218	2	General Motors New Look
Medicine Hat Transit Medicine Hat, Manitoba	1/90	New	6V-92T	Methanol	D. Gaze (403) 529-8218	3	MCI Classic
Orange County Transit Orange County, CA	4/6/90	New	L-10	Methanol/Avocet	E. Medellin (714) 638-9250	2	Gillig
Phoenix Transit System Phoenix, AZ	6/89	New	6V-92	Methanol	T. J. Ross (602) 262-7867	2	Transportation Manufacturing Company

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Source: "Summary of Alternative Fuel/Clean Air Technology Buses in North American Transit Use." M. J. Meloche, 1990



## Summary of Alternative Fuel/Clean Air Technology Buses in North American Transit Use

# METHANOL

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## **GLOSSARY**

<b>BART</b>	<b>Bay Area Rapid Transit</b>
<b>CAAA</b>	<b>Clean Air Act Amendments of 1990</b>
<b>Caltrans</b>	<b>California Department of Transportation</b>
<b>CBE</b>	<b>Citizens for a Better Environment</b>
<b>CEQA</b>	<b>California Environmental Policy Act</b>
<b>CNG</b>	<b>Compressed Natural Gas</b>
<b>DOE</b>	<b>Department of Energy</b>
<b>DOT</b>	<b>Department of Transportation</b>
<b>EPA</b>	<b>Environmental Protection Agency</b>
<b>GRI</b>	<b>Gas Research Institute</b>
<b>ITE</b>	<b>Institute of Transportation Engineers</b>
<b>LEV</b>	<b>Low Emitting Vehicle</b>
<b>LPG</b>	<b>Liquified Petroleum Gas</b>
<b>MAG</b>	<b>Maricopa Association of Governments</b>
<b>MPO</b>	<b>Metropolitan Planning Organization</b>
<b>NARC</b>	<b>National Association of Regional Councils</b>
<b>NEPA</b>	<b>National Environmental Policy Act</b>
<b>NTD</b>	<b>Neotraditional Neighborhood Design</b>
<b>OSHA</b>	<b>Occupational Safety and Health Administration</b>





RTP	Regional Transportation Plan
SAE	Society of Automotive Engineers
SCAQMD	South Coast Air Quality Management District
TRB	Transportation Research Board
TRIS	Technical Retrieval Information Service
TSC	Transportation Systems Center
UMTA	Urban Mass Transit Administration
UTPS	Urban Transportation Planning System
VMT	Vehicle Miles Travelled
VOC	Volatile Organic Compound



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